

## THREE DIMENSIONAL IMAGING SYSTEM

This invention relates to an optical system for producing multiple images of an object field, in which at least two images are produced simultaneously under different imaging conditions. The invention has applicability in fields including optical information storage, in vivo microscopy, ophthalmic optics, wavefront analysis and the imaging of three-dimensional object fields.

The use of a diffraction grating combined with an imaging lens to produce identical images of an object field in several diffraction orders is known. Phase-only gratings, amplitude-only gratings and phase and amplitude gratings may be used to change the fraction of the energy in each diffraction order and thus to vary the relative brightness of each identical image.

The imaging of a three-dimensional object using a 'through-focal series' is also known. By this method a sequence of images of the object are taken with the optical system focused on different planes in the object field. An alternative approach forms simultaneously a matrix of images recorded through a matrix of lenses, each of which provides a different focus condition.

A disadvantage of the 'through-focal series' is that because the images are recorded sequentially it is not suited to imaging the three-dimensional structure of dynamic processes. A disadvantage of the second approach is its complex design and that the resolution obtained is limited to the resolution delivered by the individual lenses in the array, the diameter of each of which (thus image resolution) is constrained by the space into which the array may be packed.

International patent application PCT 99/00658 describes another three-dimensional imaging system. However, a disadvantage of that system is that the optical transfer functions appropriate to the images formed in diffraction orders located symmetrically with respect to the undiffracted beam must suffer equal and opposite distortions compared to the beam in the zero order.

The storage of data in three dimensional, optically readable, storage media is also known (S Jutamulia and G M Stori, 'Three-Dimensional Optical Digital Memory', Optoelectronics -

Devices and Technologies Vol 10, No. 3, pp343-360, 1995 and K Kobayashi and S S Kano, 'Multi-Layered Optical Storage with Nonlinear Read/Write', Optical Review, Vol 2, No 1, pp20-23, 1995). These papers review the media and architecture for various three dimensional optical memories.

In a high performance, near diffraction limited optical system such as a compact disk player, all sources of wavefront aberrations must be considered. In a standard compact disk, the data layer is covered with a substrate several hundred microns thick. Propagation of light through this substrate (which is essentially a parallel plate) introduces spherical aberration, increasing the spot size on the data layer and degrading resolution. This effect is overcome in conventional, single layer, compact disk systems by building spherical aberration correction into the objective lens.

In a multi-layer optical data storage medium the degree of spherical aberration is dependent on the depth of the data layer below the surface, hence when reading from each distinct layer a different level of spherical aberration correction is required. An aberration-corrected objective lens is therefore not sufficient. Several patents on multi-layer optical data storage systems, which rely on a moving lens to focus at different depths, have suggested ways of performing 'active' spherical aberration correction. US 5202875 suggests using a stepped block of substrate material which is moved across the optical beam (using a voice coil motor) to a position dependent on the layer being read, such that the thickness of material that the beam passes through is constant. Other suggestions include a pair of prisms, one of which is translated, a rotating disk of variable thickness and movable compensation plates.

All of these approaches introduce additional moving parts and complexity into the system.

According to this invention, an apparatus for producing simultaneously a plurality of spatially separated images from an object field comprises:

an optical system arranged to produce an image associated with a first optical transfer function;  
a diffraction grating arranged to produce, in concert with the optical system, images associated with each diffraction order ;

ancillary optical modules operating on individual diffraction orders and

means for detecting the images,

wherein the optical system, diffraction grating and detecting means are located on an optical axis, the diffraction grating is located in a suitable grating plane and the ancillary optical modules modify the optical transfer functions associated with the images.

The invention utilises a single lens or multiple lens system with a diffraction grating and ancillary optical modules to produce simultaneously a set of images of the object field in which each image in the set can correspond to an image of the object field recorded under different focus conditions but in which the full diameter of the lens system is exploited in each image in the set. For each image in the set, the full resolution and depth of field of the imaging means is exploited.

The ancillary optical modules contain optical elements which may also produce different amounts of spherical aberration in each diffraction order. This could be used to correct for spherical aberration in the associated optical system.

The grating used can be a single diffraction grating or a series of such gratings. The gratings used may be produced by computer-generated (digitised in space and/or in amplitude) or by analogue (e.g. interferometric) means.

The present invention allows for the optical transfer functions appropriate to the images formed in different diffraction orders to be independent of, identical with or correlated to the distortions applicable to any other diffraction order.

In the following descriptions detector means a detection means comprising a spatially-resolving system such as a pixellated array of detector elements e.g. a charge coupled device (CCD). For